

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY)

2. REPORT TYPE
Technical Papers

3. DATES COVERED (From - To)

4. TITLE AND SUBTITLE

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

8. PERFORMING ORGANIZATION
REPORT

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

10. SPONSOR/MONITOR'S
ACRONYM(S)

11. SPONSOR/MONITOR'S
NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

20030206 072

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:

a. REPORT

Unclassified

b. ABSTRACT

Unclassified

c. THIS PAGE

Unclassified

17. LIMITATION
OF ABSTRACT

A

18. NUMBER
OF PAGES

19a. NAME OF RESPONSIBLE
PERSON

Leilani Richardson

19b. TELEPHONE NUMBER

(include area code)
(661) 275-5015

99-0104

✓ Spreadsheet
✓ DTS

MEMORANDUM FOR PRR (Contractor/In-House Publication)

FROM: PROI (TI) (STINFO)

20 May 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0104
Law Levine. "AFRL Propulsion Directorate Propulsion Sciences & Advanced Concepts Division"

~~(Foreign Release)~~

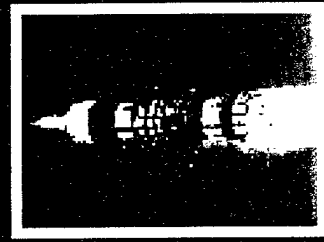
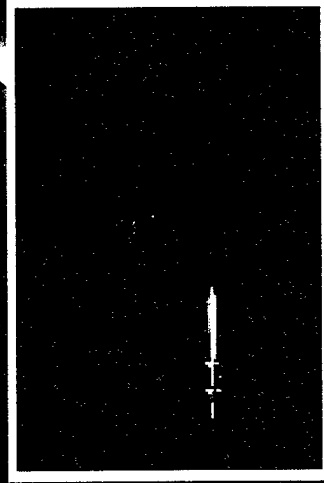
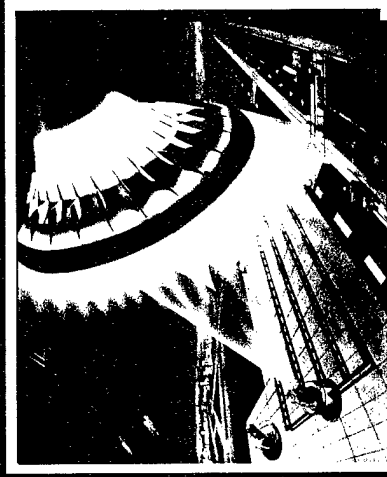
Dist A



Air Force Research Laboratory

Propulsion Directorate

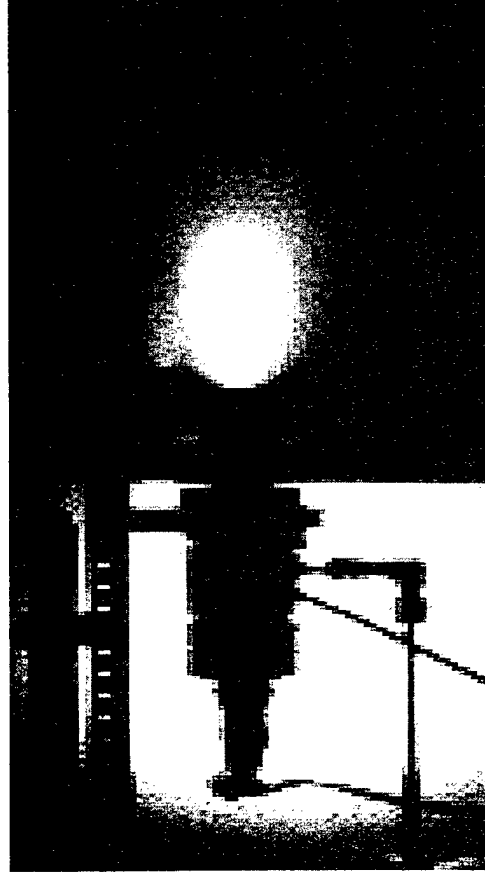
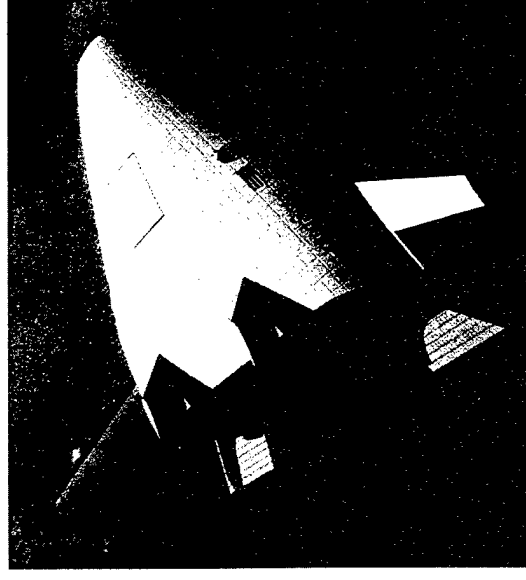
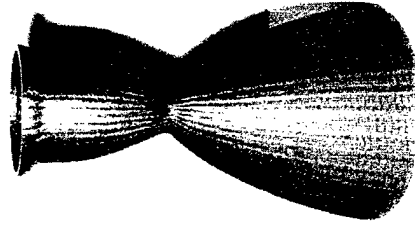
Propulsion Sciences & Advanced Concepts Division





Rocket-Propulsion Research

- Advanced propellants
- Propulsion materials and components
- Aerophysics





Propulsion Sciences & Advanced Concepts Division

Edwards AFB CA

Dr. Steve Rodgers 525-5230
Dr. Phil Kessel 525-5591

Aerophysics
Jay Levine
525-6179

**Propulsion Material
Applications**
Maj Mike MacLachlan
525-5230

Propellants
Dr. Pat Carrick
525-5883

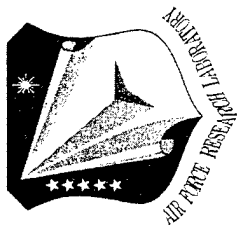
Wright-Patterson AFB OH

Lubrication
Maj Walt Lauderdale
785-5568

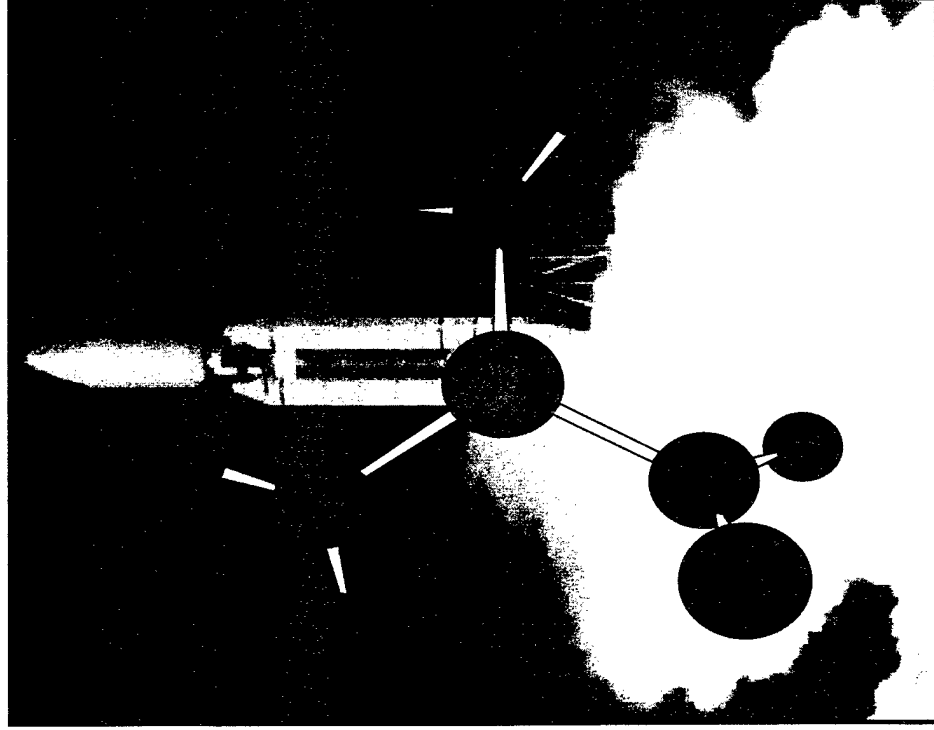
Combustion
Charlotte Eigel
785-6814

Fuels
Bill Harrison
785-6601

High Speed Systems
Maj Kenneth Phillipart
785-5221



Technical Specialties



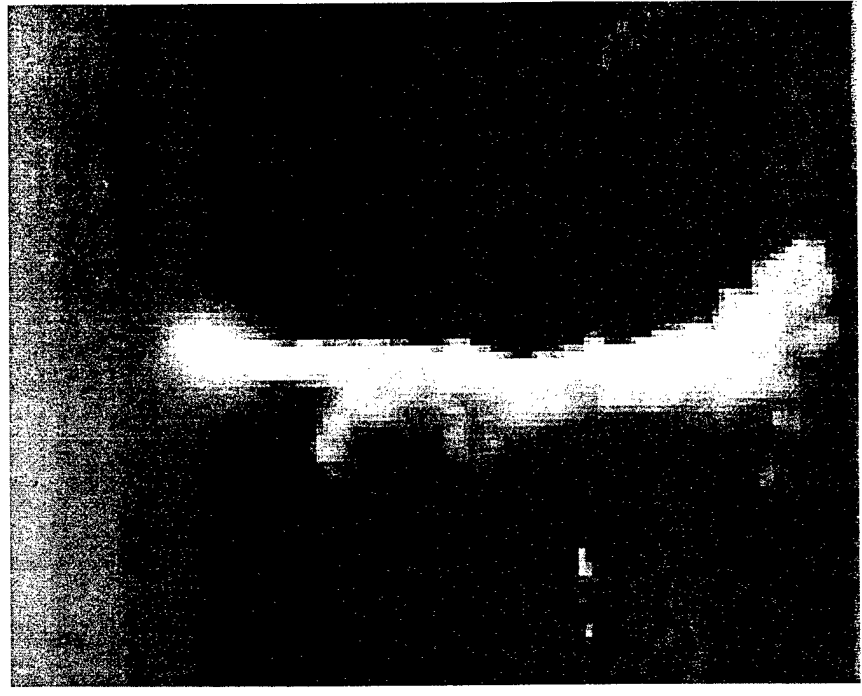
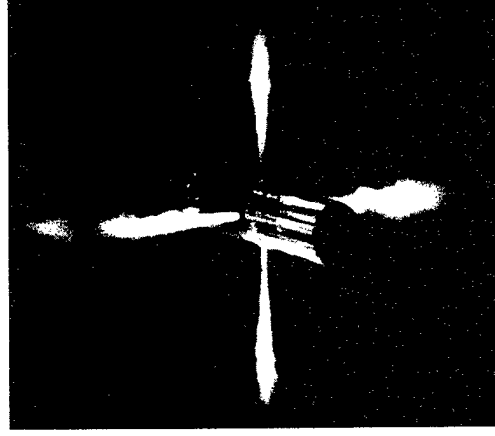
- Combustion
- Hypersonics
- Lubricants and mechanical systems
- Advanced-concept system analysis
- Fuels and propellants
- Plume phenomenology
- Advanced components



Aerophysics

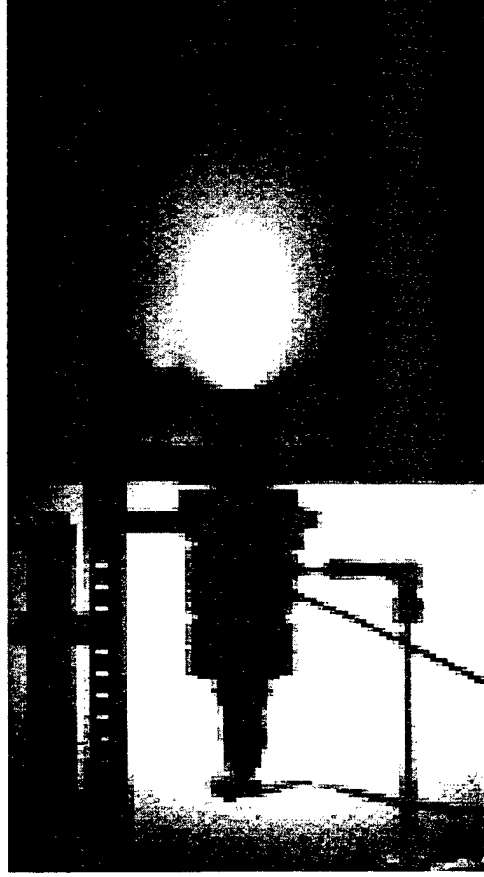
Rocket Combustion—from Propellant Injection to Plume Dissipation

- Non-equilibrium flows
- Supercritical combustion
- Plumes





Nonequilibrium Flow Phenomena



Microthruster concept (1 to 100 μ N thrust range)

Payoff

- Reduced production/launch costs for satellites
- Robust tracking via dual mode IR / UV sensors
- Increased spacecraft lifetime & survivability
- Speed deployment of new energetic propellants

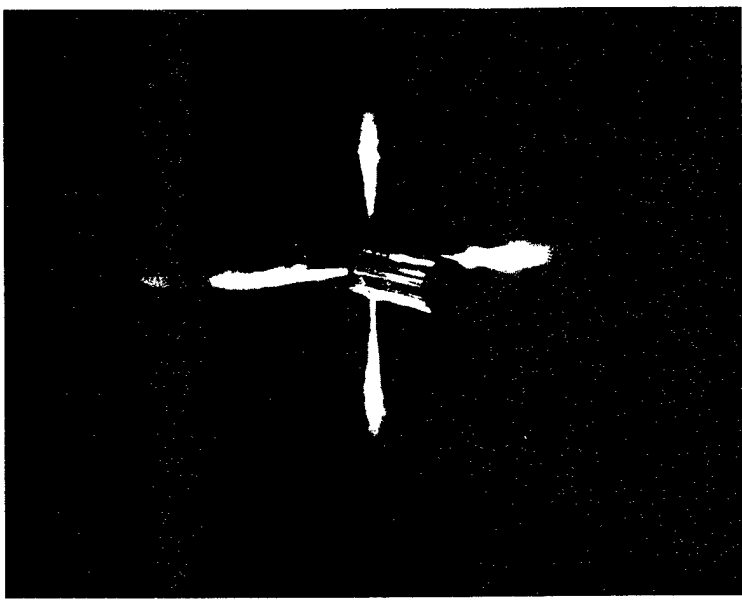
Goals

- Identify the key mechanisms which control:
 - The performance characteristics of microthrusters
 - The intensity and spectrum of plume radiation signatures
 - The decomposition and combustion of emerging energetic materials
 - Contamination effects on spacecraft systems
- Design and evaluate novel microthruster concepts
- Provide 3D simulation tools for signature/contamination modeling



Air Force Micropropulsion Mission Requirements

- Near-Earth orbital maneuver requirements
 - Fast response time \Rightarrow High thrust
 - Kinetic kill \Rightarrow Very high thrust
 - Many maneuvers \Rightarrow High specific impulse
- Satellite size requirements
 - Microsatellites (1 g to 1 kg) \Rightarrow Communication/surveillance constellations
 - Small satellites (> 100 kg) \Rightarrow Dedicated satellite communication and surveillance
- A whole range of thrusters is needed to fulfill this broad spectrum of requirements \Rightarrow Chemical, solid, electric, PDE
- Simple scaled-down versions of existing thrusters do not maintain performance levels needed \Rightarrow Critical need for advanced propulsion concepts and approaches

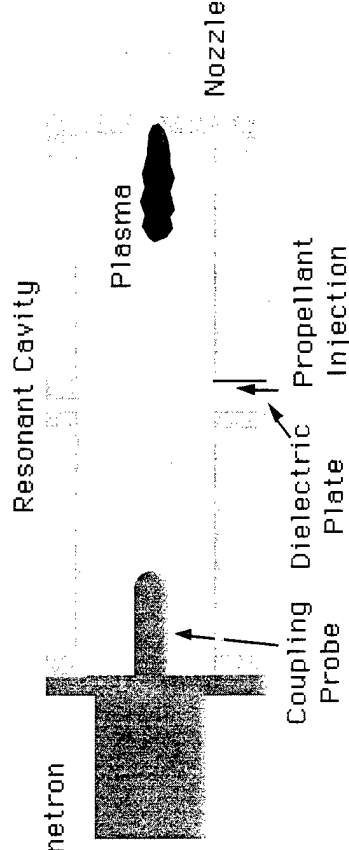




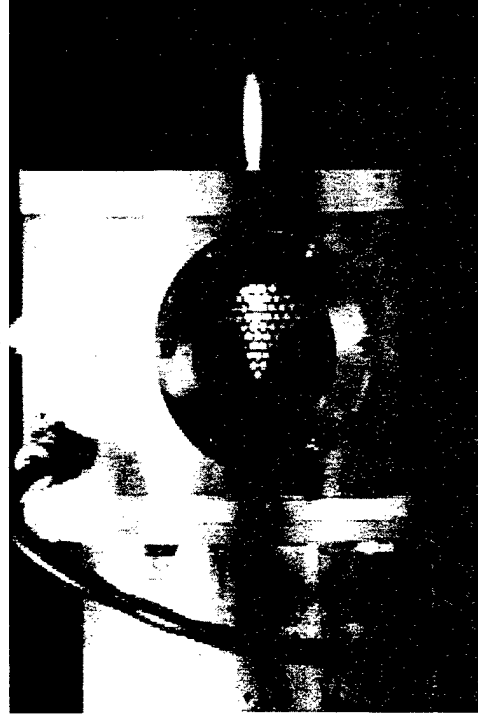
Microwave Microthruster

Description

- Electrodeless, vortex-stabilized arcjet thruster
- Higher specific impulse than chemical systems; more thrust than higher specific-impulse electric devices
- Reduced erosion; increased payload mass; increased lifetime
- Broad range of propellants: N_2 , He, H_2 , NH_3 , H_2O
- Broad range of power levels: 60 watts - 30 kilowatts
⇒ Versatile mission profile



Operation: Magnetron converts electrical energy to microwaves that heat propellant gases to plasma temperatures.



10-cm-diameter thruster operating at 5 kW

Mission Applications

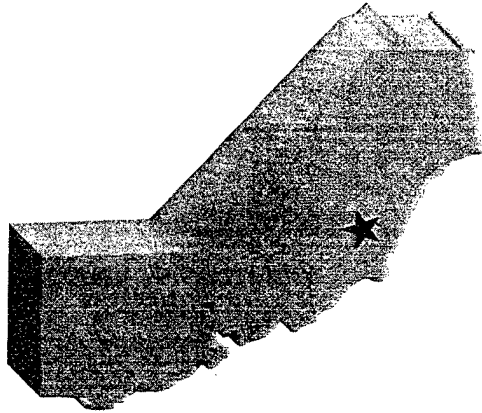
- Station keeping, attitude control, orbit boost
- Systems : Spartan, Mighty Sat, International Space Station, Shuttle payload boost

Program

- Improve thrust and efficiency by reducing energy loss (heat) to the boundary layer through viscous dissipation
- Joint experimental and analytical effort by AFRL/PRS with Penn State University

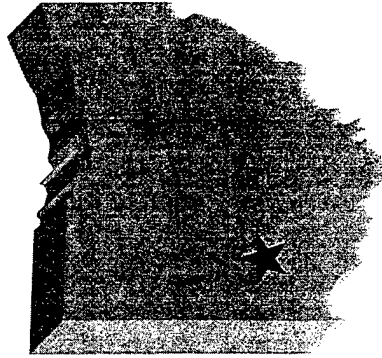


Comprehensive Propulsion Research



Rocket Propulsion

Liquid
Solid
Hybrid
RBCC
PDRE



Airbreathing Propulsion

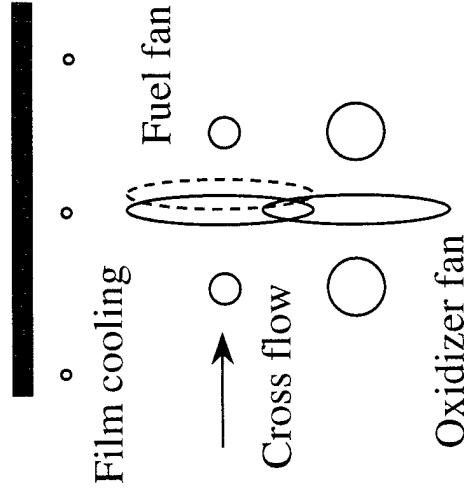
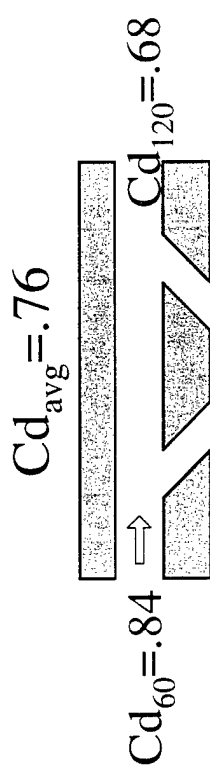
Ramjet
Scramjet
TBCC
RBCC
PDE

*Combined Rocket and
Aeropropulsion expertise*

— Air Force Research Laboratory —

Manifold Cross Flow Can Cause Fan Misalignments and Reduce Chamber Lifetime

A variation in discharge coefficient could shift the spray angle, potentially allowing oxidizer to reach the wall and cause failure or reduce lifetime.



Cant angles as large as 13° have been predicted. Misalignment in the Fastac outer row would be 5° at most.

- Optimum
- - - Potential misalignment due to cross flow effects



Potential canting

--- *Air Force Research Laboratory* ---

COLD FLOW INJECTOR CHARACTERIZATION FACILITY

Hardware

Gas simulants N₂(g), He(g)
Liquid simulant H₂O(l)
Window Purge gas N₂(g), He(g)
N₂ mass flow rate .20 lbm/s
He mass flow rate .20 lbm/s
H₂O mass flow rate 4.0 lbm/s
Max. test art. press. 2000 psi.
Max. Fuel sim. press. 3000 psi.
Max. Ox sim. press. 3000 psi.
Electrical connections 120V, 208V (1φ:
 10A, 3φ 20A and
 50A).

Windowed test chamber with 5.5" of axial injector travel and a linear translating injector stage with 5" total radial travel inside chamber.

Ability to simulate manifold cross velocities to 30 ft/s

Data acquisition and control

16 Channel, 12 Bit National Instruments A/D board run by a 486/33 PC running MS Quick Basic.

Allen-Bradley PLC system for Remote Valve Operation

Mechanical Diagnostics

27 tube traversable linear patternator

Optical Diagnostics

Oxford 20 kHz, 20W Cu vapor laser.
Innova 4W and 10W Argon Ion lasers.
Inj. seed, 2 plse Yag (1.5J at 1064 nm)
Continuum ND6000 Dye laser.
Princ. Inst and Stanford gated CCD cams.
Infinity and Questar LD microscopes.
Aerometrics 2 comp. PDPA.
Malvern 2600 particle sizer.
CCD camera with strobelight and VCR

Injector/Combustor Technology

Air Force Research Laboratory

SUPERCRITICAL DROP/JET INJECTION FACILITY

Hardware

Chamber

Stainless

Optical access

2 facing sapphire windows of 5.25" dia
2 facing slot-shaped quartz (4.75"x0.50")

Max chamb. press.

2000 psi

Chamb. temp.

473 K

Injected fluid

O₂, N₂, HC, and mixtures

Ambient fluid

N₂, He, and mixtures

Injected mass flow rate

400 mg/s

Cryogenic cooler

85 K

Mass flowmeters

up to 10,000 SLPM

Gas detection

O₂, CO, HC

Electrical connections

120V, 208V (1 ϕ :

20A, 3 ϕ 30A and

50A).

Data acquisition and control

64-channel National Instrument AMUX-64T analog multiplexer with special provision for temperature sensor.NB-MIO-16X multifunction I/O board with analog-to-digital converter for Macintosh NuBus computer.

Labmaster DMA Counter/timer/ ADC/Digital I/O

Scion Corp frame grabber

LabView GUI control interface.

Several PC and Power Macintosh

HP programmable timing/pulse generator

Optics

Infinity long-distance microscope

PL-8010 Continuum Nd:YAG pulsed dye laser,

high speed strobe light,

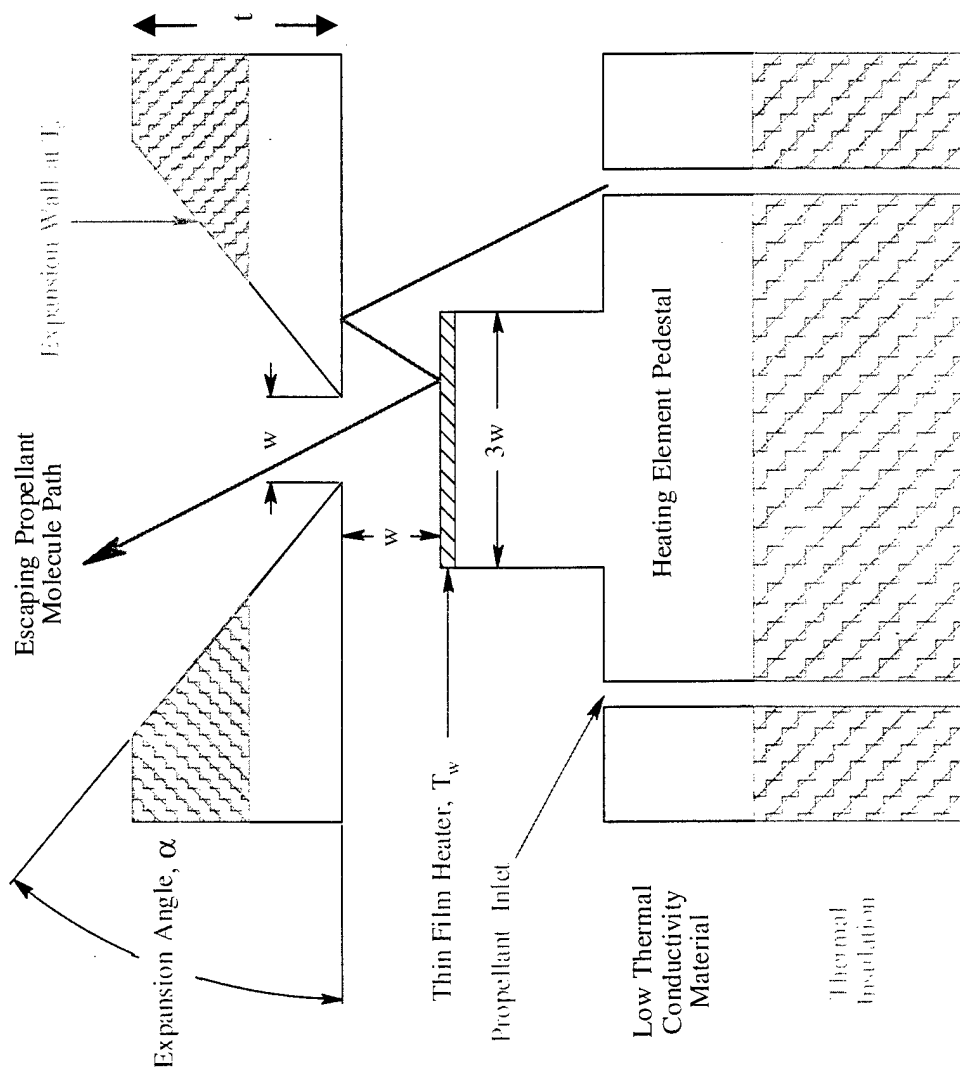
Princeton Instrument camera,

Interlaced PULNix CCD camera

Injector/Combustor Technology



FMMR Design



Valve, Filter, Propellant Tank

$w \sim 1 \text{ to } 100 \mu\text{m}$
 $T_w \sim 600 \text{ to } 1200 \text{ K}$
 $\alpha = 54.74^\circ$
 $t \sim 100 - 250 \mu\text{m}$

Desired:

$w = 100 \mu\text{m}$
 $T_w = 600 \text{ K}$
 $\alpha = 54.74^\circ$
 $t = 200 \mu\text{m}$
 Slot length = 1 cm
 No. of slots = 40

PERSONNEL



Aerophysics Branch Organization (PRSA)

Branch Chief : Jay Levine

Marietta Krissack : Secretary (Shared with other Branches)
Chris Sandstrom : Administration and finance (Shared with other Branches)

Working Groups

Plumes (Tom Smith)

1. Marty Verner
2. Dustin Ziegler
3. Roy Hilton
4. [REDACTED]
5. Robert Lyon
6. Alan Kawasaki
7. Bill Calhoon

Combustion Devices (Doug Talley)

1. Victor Burnley
2. Rodger Benedict
3. Ed Coy
4. Pete Strakey
5. Cliff Lusby
6. Mike McKeel
7. Richard Cohn

Nonequilibrium Flows (Ingrig Wyson)

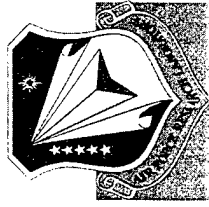
1. Andrew Ketsdever
2. David Campbell
3. Dean Wadsworth
4. Ghanshyam Vaghjiani
5. Angelo Alfano

8. Tim Auyeung
9. Mike Griggs
10. Bruce Cheroudi
11. Mark Wilson

Palace Knights

Ron Bates : Stanford
Mark Archambault : Stanford

6/99
5/99



PRESSURE DEPENDENT MIXING LAYER STRUCTURE

Nitrogen/nitrogen system ($P_{cr} = 493$ psi, $T_{cr} = 126$ K)

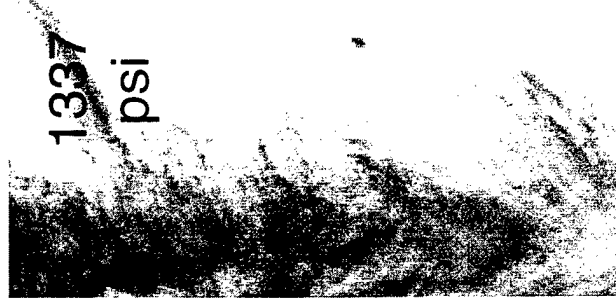
$T_{inj} = 128$ K, $T_{amb} = 300$ K, mass flow = 350 mg/s



Low Pres.
Subcritical
Droplets



Mod. Pres.
Supercritical
Ligaments



High Pres.
Supercritical
Gas layers



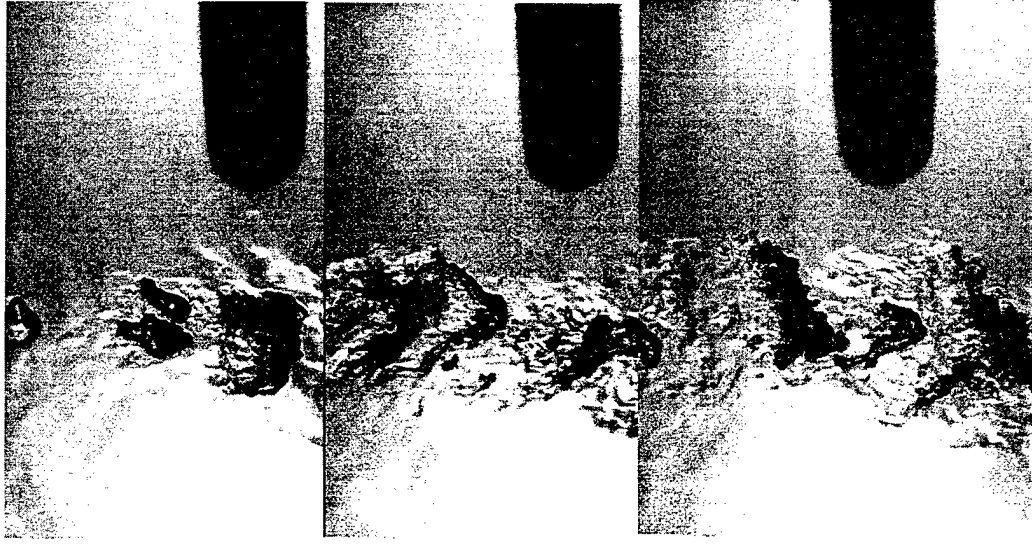
High Pressure and Supercritical Combustion (6.1)

OBJECTIVE

Determine the mechanisms which control the breakup, transport, mixing, and combustion of supercritical droplets, jets, and sprays.

APPROACH

- Piezoelectric cryogenic jet and drop generator in chilled helium.
- Produce acoustic waves using metallic actuators, design resonant modes, focus acoustic waves.
- Reduce optical path lengths.
- Use spontaneous Raman scattering from a frequency doubled Nd-YAG laser.



*Transcritical Oxygen Drops
in Nitrogen*

Basic Research in Nonequilibrium Flow Phenomena



Objectives/Goals

- Identify the key mechanisms which control:
 - The performance characteristics of micro-thrusters
 - The intensity and spectrum of plume radiation signatures
 - The decomposition and combustion of emerging energetic materials
 - Contamination effects on spacecraft systems
- Design and evaluate novel microthruster concepts
- Provide 3D simulation tools for signature/contamination modeling of missiles and spacecraft

